Soybean Development and Yield as Affected by Three Postemergence Herbicides

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ABSTRACT

Field experiments were conducted during 3 yr at four locations in Illinois and three locations in Iowa to evaluate the influence of soybean [*Glycine max* (L.) Merr.] planting date and postemergence herbicide application timing on soybean injury and grain yield. Glyphosate [*N*-(phosphonomethyl)glycine] at 1120 g a.e. ha^{-1} did not cause visual soybean injury or reduce yield. Acifluorfen [5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid] at 420 g a.i. ha^{-1}, and imazethapyr [2-[4,5-hydro-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid] at 70 g a.i. ha^{-1} caused visual soybean injury at 5 to 7 and 21 to 24 d after herbicide application (DAA). Overall soybean injury was greater with the late planting date compared with the early planting date. Chlorosis and stunting at 5 to 7 DAA was greater from acifluorfen and imazethapyr at the early (V2–V3 soybean stage) compared with the late (V5–V6 soybean stage) application timing. Imazethapyr and acifluorfen reduced soybean leaf area index by 5.7 to 14.3% and soybean height by 4.1 to 8.3% at 21 to 24 DAA. Soybean yield was reduced 1.5 and 2.1% by acifluorfen and imazethapyr, respectively, compared with the no-herbicide/weed-free plots. Soybean yield averaged across herbicide treatment and application timing was reduced 11% with the late planting date compared with the early planting date.

Soybean injury from postemergence herbicides continues to be a major concern of soybean producers. Before the introduction of glyphosate-resistant soybean, noninjurious herbicide options for postemergence control of broadleaf weeds in soybean were limited. Several studies have reported no significant visual injury to glyphosate-resistant soybean from glyphosate (Culpepper et al., 2000; Lich et al., 1997; Nelson and Renner, 2001). The low risk of injury from glyphosate to glyphosate-resistant soybean has contributed to the rapid adoption of this technology by producers. However, research has indicated that glyphosate may not provide complete control of some weed species (Culpepper et al., 2000; Gonzini et al., 1999; Lich et al., 1997). Therefore, soybean producers may elect to apply supplemental postemergence herbicides to glyphosate-resistant soybean to improve weed control.

The majority of the postemergence herbicides used in soybean are diphenylethers, acetolactate synthase (ALS) inhibitors or glyphosate. Diphenylether herbicides such as acifluorfen and lactofen [(±)-2-ethoxy-1-methyl-2-oxyethyl 5-[2-chloro-4-(trifluoromethyl) phenoxy]-2-nitrobenzoate] typically cause necrosis of soybean leaf tissue present at the time of application and crinkling and necrosis of leaves that emerge shortly after application (Kapusta et al., 1986; Wichert and Talbert, 1993). Soybean stunting and chlorosis was observed from herbicides that inhibit the ALS enzyme such as imazethapyr (Hart and Roskamp, 1998; Hart et al., 1997). Recent studies have also reported injury to glyphosate-resistant soybean treated with glyphosate (Weber and Kapusta, 1998; Young and Young, 2000). Although soybean plants usually recover from herbicide injury as the season progresses, producers question if crop stress from postemergence herbicide injury ultimately results in reduced soybean yield.

The amount of soybean injury observed with postemergence herbicides varies with soybean growth stage. Soybean was more sensitive to acifluorfen at the V3 stage of soybean growth compared with the V5 stage (Kapusta et al., 1986). Similarly, applications of imazethapyr caused greater soybean injury when applied to soybean at the V1 stage compared with V2 (Hart et al., 1997). In contrast, Weber and Kapusta (1998) observed 5 to 23% soybean injury from glyphosate applied at the V5 stage of soybean growth, but no soybean injury from glyphosate applications made earlier in the season. Other researchers have reported soybean injury from late season glyphosate applications (Young and Young, 2000).

Soybean planting date may also impact the effect of herbicide injury on soybean yield since later-planted soybean has less time to recover from injury before physiological maturity. Soybean that is double cropped after wheat typically experience a shorter growing season than soybean grown as the primary crop. In research evaluating the impact of herbicide injury on yield of glyphosate-resistant soybean planted in late June and early July, imazamox [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid] reduced soybean yield by 18% (Krausz and Young, 2001).

The influence of planting date and application timing of postemergence herbicides on soybean injury and subsequent yield has not been adequately evaluated. Therefore, the objective of this research was to determine the effects of soybean planting date and herbicide application timing on herbicide injury and yield of glyphosate-resistant soybean grown under different environments.

MATERIALS AND METHODS

Field studies were conducted in 1997, 1998, and 1999 at four locations in Illinois and three locations in Iowa (Table 1).

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Abbreviations: a.e., acid equivalent; a.i., active ingredient; DAA, days after application; EPOST, early postemergence; LAI, leaf area index; LPOST, late postemergence.

Table 1. Environments, planting dates, and herbicide application dates used to evaluate the effect of postemergence herbicide injury on soybean yield.

				Application timing	
Location	Year	Soybean cultivar	Planting date†	V2–V3	V5–V6
Ames, IA	1997	Asgrow 2901RR	1–14 May	26 June	9 July
			2–5 June	1 July	12 July
Ames, IA	1998	Asgrow 2901RR	1–7 May	8 June	22 June
			2–4 June	23 June	6 July
Ames, IA	1999	Asgrow 2901RR	1–10 May	14 June	26 June
			2–7 June	7 July	21 July
Crawfordsville, IA	1997	Asgrow 2901RR	1–6 May	13 June	27 June
			2–3 June	27 June	10 July
Crawfordsville, IA	1998	Asgrow 2901RR	1–13 May	12 June	22 June
			2–4 June	7 July	11 July
Crawfordsville, IA	1999	Asgrow 2901RR	1–3 May	10 June	18 June
			2–26 May	18 June	30 June
Nashua, IA	1997	Asgrow 2901RR	1–15 May	18 June	30 June
			2–4 June	30 June	10 July
Nashua, IA	1998	Asgrow 2901RR	1–11 May	16 June	23 June
			2–3 June	2 July	8 July
Nashua, IA	1999	Asgrow 2901RR	1–25 May	24 June	7 July
			2–14 June	22 June	30 July
Belleville, IL	1997	Asgrow 3601RR	1–9 May	16 June	24 June
			2–29 May	24 June	3 July
Belleville, IL	1998	Asgrow 4501RR	1–14 May	9 June	22 June
			2–3 June	30 June	6 July
Belleville, IL	1999	Asgrow 3701RR	1–11 May	11 June	24 June
			2–4 June	24 June	9 July
Dekalb, IL	1997	Pioneer 9294RR	1–7 May	19 June	27 June
			2–5 June	27 June	7 July
Dekalb, IL	1998	Pioneer 9294RR	1–19 May	22 June	6 July
			2–8 June	6 July	21 July
Dekalb, IL	1999	Pioneer 92B71RR	1–21 May	22 June	13 July
			2–10 June	13 July	28 July
Monmouth, IL	1997	Pioneer 9363RR	1–6 May	19 June	26 June
			2–3 June	26 June	1 July
Monmouth, IL	1998	Pioneer 9363RR	1–6 May	10 June	23 June
			2–7 June	29 June	8 July
Monmouth, IL	1999	Asgrow 3002RR	1–7 May	9 June	29 June
			2–7 June	29 June	12 July
Urbana, IL	1997	Pioneer 92B71RR	1–7 May	17 June	26 June
			2–5 June	30 June	15 July
Urbana, IL	1998	Pioneer 9363RR	1–28 May	25 June	6 July
			2–26 June	17 July	3 August
Urbana, IL	1999	Pioneer 9363RR	1–27 May	21 June	29 June
			2–17 June	9 July	16 July

† 1 = the first planting date; 2 = the second planting date at each location.

The locations represented a variety of environments across the two states. Two planting dates were established at each location, the first in early spring as weather permitted and the second approximately 1 mo later (Table 1). A glyphosate-resistant soybean variety adapted to each location was planted in 76-cm rows into a conventional or reduced tillage seedbed for both planting dates. Plots were six rows wide and 9 to 12 m in length. Each treatment was replicated four times. Soybean seeding rates, planting depth, fertility, and seedbed preparation techniques were based on local production practices at each location. All plots were maintained weed free throughout the season by handweeding and cultivation to eliminate yield loss due to weed interference.

Herbicide treatments that were evaluated included glyphosate at 1120 g a.e. ha^{-1} plus ammonium sulfate at 2% w/w, imazethapyr at 70 g a.i. ha^{-1} plus methylated seed oil at 1% v/v plus 28% urea ammonium nitrate at 1.25 to 2% v/v, acifluorfen at 420 g a.i. ha^{-1} plus crop oil concentrate at 1% v/v, and a nontreated control. Within each planting date, herbicides were applied at two application timings that included V2 to V3 and V5 to V6 soybean stages (Fehr and Caviness, 1977). These stages represented early postemergence (EPOST) and late postemergence (LPOST) application timings, respectively (Table 1).

Visual estimates of soybean chlorosis, stunting, and overall injury on a 0 (no chlorosis, stunting, or injury) to 100 (plant death) scale were made 5 to 7 and 21 to 24 d after each herbicide application (DAA). Herbicide injury was also assessed at 21 to 24 DAA by measuring the height of 10 soybean plants in each plot, determining leaf area index (LAI) with the LAI-2000 plant canopy analyzer (LI-COR, Lincoln, NE), and collecting aboveground biomass samples. Biomass sampling consisted of counting and hand harvesting the soybean in a 1-m row subplot. Three uniform plants from each subplot were selected and divided into leaves, stems and petioles, and pods for dry weight analysis. Harvest index and components were determined in each plot after 99% leaf senescence. Harvest index represents the seed dry weight per total plant dry matter weight within a 1-m row subplot. Within each subplot, soybean plants were counted and hand harvested with three representative plants selected and divided into pod shells, seeds, and stems and petioles for dry weight analysis. Soybean height at harvest was also determined by averaging the height of 10 soybean plants chosen arbitrarily in each plot. Soybean yield was determined by harvesting the center two rows of each plot and adjusting the grain to 13% moisture.

Fixed and random effects as well as their interactions were evaluated using a split-plot ANOVA. Environment, replications, and their interactions were considered random effects. Plant height, leaf area index, harvest index, and grain yield were tested as percent of the nontreated control within each environment. Subplot treatment means within each main-plot

Table 2. Analysis of variance significance levels for main effects and interactions of planting date, herbicide treatment, and application timing for soybean injury and reductions in soybean height, leaf area index, harvest index, and yield.

	5–7 d after treatment			21–24 d after treatment					Harvest		
Source of variation	Chlorosis	Stunting	Overall injury	Chlorosis	Stunting	Overall injury	Height reduction	Leaf area index reduction	Height reduction	Harvest index reduction	Yield reduction
Planting date (P)	***	**	**	**	NS†	***	NS	NS	NS	NS	NS
Herbicide (H)	***	***	***	***	***	***	***	***	***	NS	***
Timing(T)	*	***	***	NS	**	NS	**	***	***	NS	NS
P × H	**	***	NS	**	NS	NS	NS	NS	NS	NS	NS
H × T	*	**	***	NS	NS	NS	***	*	NS	NS	NS
P × T	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
P × H × T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.
† NS, not significant.

were separated when significant using Fisher's protected LSD ($p = 0.05$).

RESULTS AND DISCUSSION

There was an interaction between herbicide and planting date for chlorosis and stunting at 5 to 7 DAA (Table 2). Soybean chlorosis from acifluorfen was 6.9 and 9.3% at 5 to 7 DAA with the early and late planting dates, respectively (Table 3). However, there was no difference in stunting from acifluorfen between planting dates. Chlorosis and stunting from imazethapyr were greater with the late planting date compared with early planting while chlorosis and stunting from glyphosate was <1% at 5 to 7 DAA, regardless of soybean planting date. Greater chlorosis from acifluorfen compared with glyphosate at 5 to 7 DAA was expected since injury symptoms from acifluorfen are usually visible in 1 to 2 d compared with 10 to 20 d with glyphosate (Vencill, 2002). Chlorosis, stunting, and overall injury 5 to 7 DAA were affected by an interaction between herbicide and application timing (Table 2). Greater chlorosis and stunting were observed from imazethapyr and acifluorfen at the EPOST timing compared with LPOST (Table 3). Similarly, overall injury at 5 to 7 DAA was significantly greater with acifluorfen EPOST (18%) compared with LPOST (15%). These results are in agreement with previous studies that reported greater soybean injury from acifluorfen at early application timings compared with late (Hart et al., 1997; Kapusta et al., 1986). Overall soybean injury at 5 to 7 DAA was greater with the late planting date compared with early.

Similar to 5 to 7 DAA, chlorosis from imazethapyr at 21 to 24 DAA was greater with the late compared with the early planting date (Table 3). Soybean stunting

Table 3. Soybean chlorosis, stunting, and overall injury at 5 to 7 and 21 to 24 d after treatment.

Variable		5-7 d after treatment: Chlorosis	Stunting	Overall	21–24 d after treatment: Chlorosis	Stunting	Overall
		%					
Planting date							
Early		—	—	8.4	—	—	2.1
Late		—	—	9.3	—	—	2.8
Significance level				**			***
Herbicide							
Glyphosate		—	—	—	—	0.1	0.2
Imazethapyr		—	—	—	—	3.4	3.6
Acifluorfen		—	—	—	—	3.1	3.6
LSD(0.05)						0.4	0.4
Application timing							
EPOST		—	—	—	—	2.4	—
LPOST		—	—	—	—	2.0	—
Significance level						**	
Herbicide × planting date							
Glyphosate	Early	0.2	0.0	—	0.1	—	—
Imazethapyr	Early	6.2	4.9	—	2.2	—	—
Acifluorfen	Early	6.9	6.3	—	2.5	—	—
Glyphosate	Late	0.2	0.1	—	0.2	—	—
Imazethapyr	Late	7.6	6.8	—	3.2	—	—
Acifluorfen	Late	9.3	6.2	—	2.5	—	—
LSD(0.05)		1.0	0.8	0.5			
Herbicide × application timing							
Glyphosate	EPOST	0.0	0.0	0.0	—	—	—
Imazethapyr	EPOST	7.6	6.4	10.1	—	—	—
Acifluorfen	EPOST	8.7	7.1	18.4	—	—	—
Glyphosate	LPOST	0.3	0.1	0.3	—	—	—
Imazethapyr	LPOST	6.3	5.4	9.4	—	—	—
Acifluorfen	LPOST	7.5	5.4	15.0	—	—	—
LSD(0.05)		1.0	0.8	1.0			

** Significant at the 0.01 level.
*** Significant at the 0.001 level.

21 to 24 DAA was not affected by planting date. Soybean stunting averaged over herbicide and planting date was slightly greater with the EPOST timing compared with LPOST. The main effect of herbicide was significant for both soybean stunting and overall injury at 21 to 24 DAA with similar stunting and overall injury from imazethapyr and aciflurofen and no significant soybean response from glyphosate (Tables 2 and 3). Overall soybean injury at 21 to 24 DAA was slightly greater with the late compared with the early planting date (Table 3), but was generally low.

There was an interaction between herbicide and application timing for soybean height and LAI reduction at 21 to 24 DAA (Table 2). Imazethapyr reduced soybean height by 4.5 to 5.3% with no difference between application timings (Table 4). However, the height reduction resulting from acifluorfen was greater at the EPOST timing (8.3%) compared with LPOST (4.1%). Similarly, LAI reduction was greater from acifluorfen EPOST (14.3%) compared with LPOST (6.9%). Imazethapyr reduced LAI by 5.7 to 7.3% with no significant difference between application timings. The reductions in LAI and height correspond to overall injury observed at 5 to 7 DAA. Hence, observations of herbicide injury shortly after application (5–7 DAA) were indicative of LAI and height reductions at 21 to 24 DAA. No reduction in soybean height or leaf area index was observed with glyphosate at 21 to 24 DAA (Table 4).

Averaged across planting date and application timing, height reduction at maturity was 0.8% from glyphosate, 1.9% from imazethapyr, and 2.4% from acifluorfen (Table 4). Other researchers have reported soybean height reduction at maturity from glyphosate (Elmore et al., 2001) and imazethapyr (Krausz and Young, 2001). When averaged across herbicide and planting date, slightly greater height reduction at maturity was observed at the LPOST timing (1.4%) compared with EPOST (1.2%), which is in contrast to 21 to 24 DAA when height reduction from acifluorfen was greater EPOST compared with LPOST. Harvest index was not affected by herbicide, planting date, application timing, or any interactions of those effects (Table 2).

Averaged across planting date and application timing, soybean yield was reduced 1.5% by acifluorfen and 2.1% by imazethapyr (Table 4). Acifluorfen and imazethapyr-treated plots yielded 50 and 80 kg ha^{-1} less than nontreated plots (data not shown). No reduction in soybean yield was observed with glyphosate. These results are in agreement with previous research that reported no reduction in yield of glyphosate-resistant soybean treated with glyphosate (Elmore et al., 2001; Nelson and Renner, 2001). A greater difference in grain yield was observed across planting dates when actual yield data (kg ha^{-1}) was analyzed (ANOVA not shown). Averaged across herbicide and application timing, soybean yield was 3640 kg ha^{-1} with the early planting date compared with 3230 kg ha^{-1} with the late planting date (data not shown). Thus, a 1-mo delay in soybean planting reduced yield by 11%. Other researchers have reported reductions in soybean yield as planting was delayed (Horn and Burnside, 1985; Oplinger and Philbrook, 1992).

SUMMARY

Anecdotal reports from growers linking soybean injury from postemergence herbicides to reductions in soybean yield are difficult to substantiate because of the confounding effects of weed control and environment. The influence of weed interference on soybean yield was eliminated in this research, which encompasses 252 herbicide applications made during a 3-yr period at seven different locations. Analysis of this extensive data set revealed that soybean injury from acifluorfen and imazethapyr resulted in only a 2% reduction in soybean yield. Glyphosate did not cause soybean injury or reduce yield in this research. In general, soybean injury tended to be greater with acifluorfen, the EPOST application timing, and the late planting date. However, yield reductions from acifluorfen and imazethapyr were not signifi-

Table 4. Reduction in soybean height, leaf area index, and yield from postemergence herbicide treatment.

		21–24 d after treatment		Harvest	
Variable		Height reduction	Leaf area index reduction	Height reduction	Yield reduction
		%			
Herbicide					
Glyphosate		—	—	0.8	−0.9
Imazethapyr		—	—	1.9	2.1
Acifluorfen		—	—	2.4	1.5
LSD(0.05)				0.7	1.2
Application timing					
EPOST		—	—	1.2	—
LPOST		—	—	1.4	—
Significance level				***	
Herbicide × application timing					
Glyphosate	EPOST	−0.1	1.9	—	—
Imazethapyr	EPOST	5.3	7.3	—	—
Acifluorfen	EPOST	8.3	14.3	—	—
Glyphosate	LPOST	0.1	−0.7	—	—
Imazethapyr	LPOST	4.5	5.7	—	—
Acifluorfen	LPOST	4.1	6.9	—	—
LSD(0.05)		1.7	3.3		

*** Significant at the 0.001 level.

cantly different and there was no effect of application timing on yield. Late planting had a much greater impact on soybean yield than herbicide application.

Competition from uncontrolled weeds can also have a large impact on soybean yield. Soybean yields were reduced 36% by a combination of johnsongrass [*Sorghum halepense* (L.)] and sicklepod [*Cassia obtusifolia* (L.)] (Sims and Oliver, 1990) and 46 to 50% by giant ragweed [*Ambrosia trifida* (L.)] (Baysinger and Sims, 1991). Thus, selecting a herbicide based on effectiveness for controlling the weed species present in a field is of greater importance than selecting a herbicide based on potential soybean injury and related yield loss.

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